Development of continuously frequency tunable Gyrotron and its application to 200 MHz DNP-NMR spectroscopy as a radiation source

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Abstract—**The gyrotron, Gyrotron FU CW IV continues to produce output radiation in the wide range of magnetic fields from 4.9 T to 5.2 T, and continuous frequency tuning in 6 GHz interval from 134 GHz to 140 GHz can be realized. This type of gyrotron will play an important role as a high power radiation source with the function of continuous frequency tuning to the applications in the fields of millimeter to sub-millimeter wavelength range. A sensitive NMR spectroscopy using a dynamic nuclear polarization (DNP-NMR) is the versatile analytical technique to enhance the sensitivity of the NMR spectroscopy. It is well known that the enhancement of the NMR sensitivity depends strongly on the frequency of the irradiating electromagnetic wave. This gyrotron will be applied to 200MHz DNP-NMR spectroscopy for analysis of polymer surface. Another continuous frequency tuning range (131GHz-132.5GHz) realized by this gyrotron covers that of the DNP-NMR spectroscopy with high performance.**

I. Introduction And Background

HIGH frequency gyrotrons are characterized by their ability to deliver high powers in millimeter to submillimeter wavelength range. For many applications where more intense radiation sources are required, the gyrotrons are the most promising candidates in this region of the electromagnetic spectrum. However, output frequency of the conventional high frequency gyrotron is determined by the cavity, continuous frequency tuning range will be restricted up to several tens MHz. If the high frequency gyrotron to provide the function of wide frequency tuning are developed, application of gyrotron as a radiation source will be widened.

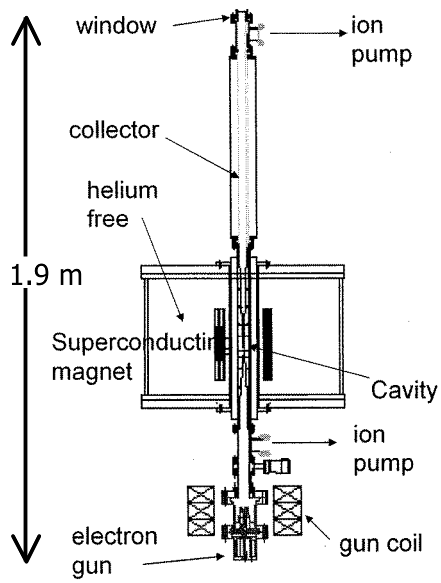
A sensitive NMR spectroscopy using a dynamic nuclear polarization (DNP) is effective in enhancing the sensitivity of this versatile analytical technique[1-4]. Such enhancement can be achieved by irradiating the sample with a beam of strong electromagnetic wave having appropriate wavelength.

II. Results

We have developed a new gyrotron, namely, Gyrotron FU CW IV, consisting of a 10 T liquid-He free superconducting magnet, a demountable tube, a vacuum pump system and power supplies. Fig. 1 shows a cross section of the Gyrotron FU CW IV

Sufficient output level (~20 W) is produced by this gyrotron. In the gyrotron, the cavity with radius of 1.915 mm and length of 20 mm is installed in the magnetic field produced by the superconducting magnet. Table 1 summarizes an output power measured by a water load together with the magnetic field intensity in the cavity region B_0, accelleration voltage of electron beam V_b, beam current I_b, cavity mode, frequency measured by the hetero-dyne detection system.

(a)



(b)

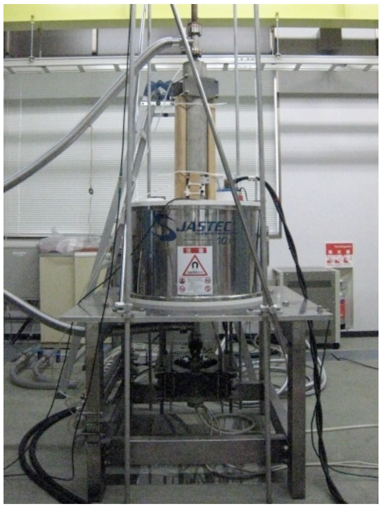


Fig. 1 (a) The cross section and (b) the photo of the Gyrotron FU CW IV.

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Fig. 2 shows the output power measured by a pyro-electric detector. The fluctuations of output power are lower than 10% for a long time interval.

Table 1. Operation parameters of gyrotron FU CW IV.

B_0 (T)	P (W)	V_b (kV)	I_b (mA)	f_{meas} (GHz)	mode	N
3.5184	57.6	19	450	96.5625	TE_{01}	1
4.9	57.6	19	450	134.182	TE_{12}	1
6.11	83.8	19	450	168.2578	TE_{22}	1
6.41	47.1	19	450	175.7958	TE_{02}	1
7.309	52.4	19	450	200.8205	TE_{32}	1
7.6476	220	19	450	209.378	TE_{13}	1
8.559	68.1	19	450	227.758	TE_{42}	1
9.06	78.6	19	450	244.3197	TE_{23}	1

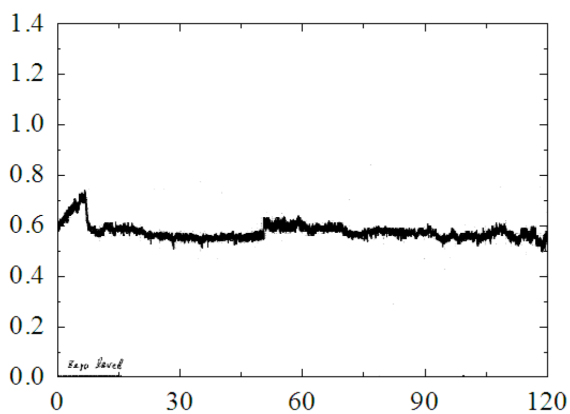

Fig. 2 The time evolution of the gyrotron output power.

The radiated power of the TE_{12} mode is observed by using a pyro-electric detector. In the experiment, the cathode voltage was adjusted at -19 kV. Although the radiated power depends on the magnetic field intensity, the gyrotron output is continuous. The frequency was measured by a hetero-dyne detection system consisting of a harmonic mixer and a synthesized CW generator as a local oscillator whose frequency stability is higher than 10^{-9} (Fig.3). The intermediate frequency signal is observed by a spectrum analyzer. The accuracy of the frequency measurement is high enough ($\sim 10^{-8}$) to determine the operating mode. Fig.4(b) shows the measured frequency as a function of the magnetic field intensity. The gyrotron output frequency continuously changes with the magnetic fields and covers a wide range from 134 GHz to 140 GHz operating on the transverse TE_{12} mode but in a sequence of different axial modes TE_{12l}. The peaks on Fig.4(a) corresponds to different indices l. The experiment verifies the feasibility of this method of tuning.

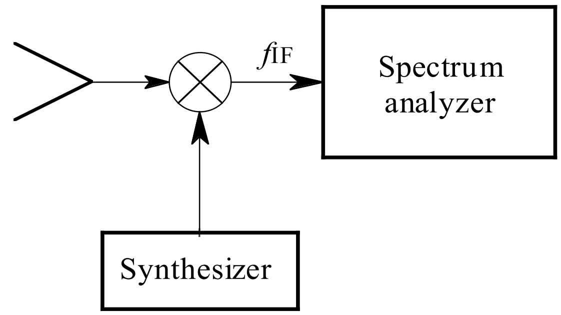

Fig. 3 The frequency measurement system consisting of synthesized CW generator as a local oscillator and harmonic mixer.

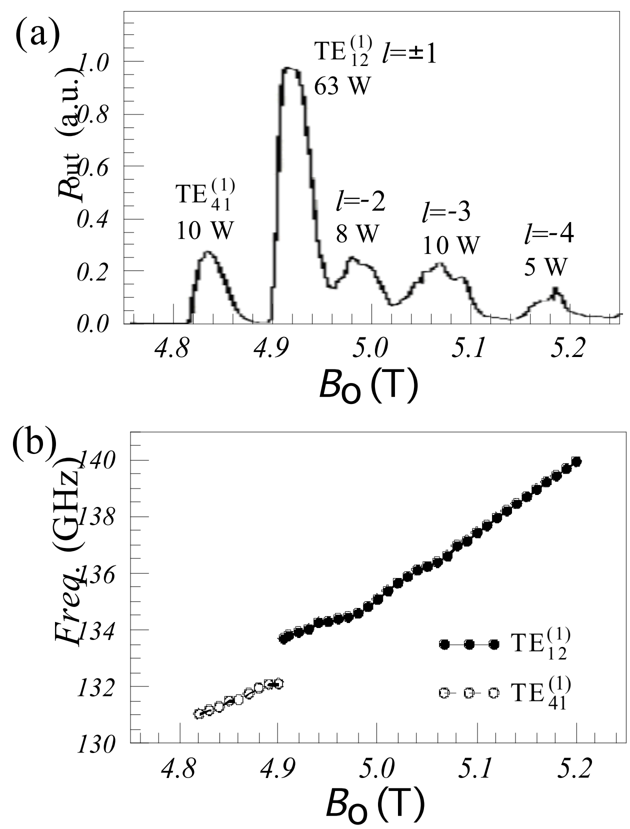

Fig.4 (a) The radiated power of TE_{12} mode and (b) the output frequency as a magnetic field intensity.

REFERENCES

[1] L. R. Becerra, *et al.*, Phys. Rev. Lett. **71**, 3561 (1993).
[2] V. Bajaj, *et al.*, J. Mag. Res. **160**, 85 (2002).
[3] M. K. Hornstein, *et al.*, IEEE Trans. Plasma Sci. **52**, 798 (2005).
[4] T. Idehara, *et al.*, Int. J. Infrared Millimeter Waves **28**, 433 (2007).